observations have been made of the variable stars in the Huygenian region. Besides these and various miscellaneous observations, measurements of several hundred close southern double-stars have been made. In addition to contributions to the American Astronomical Journal, the Sidereal Messenger and the Annals of Mathematics, the following series of publications has been issued in pamphlet form by the observatory:

1. Transit of *Venus*, December 6, 1882.
2. Tail of Comet 1882, II.
3. Nebula of *Orion*, 1885.
4. Double Stars, 1885–86.
5. Durchmusterung, — 23°.

THE LUNAR CRATER *COPERNICUS.**

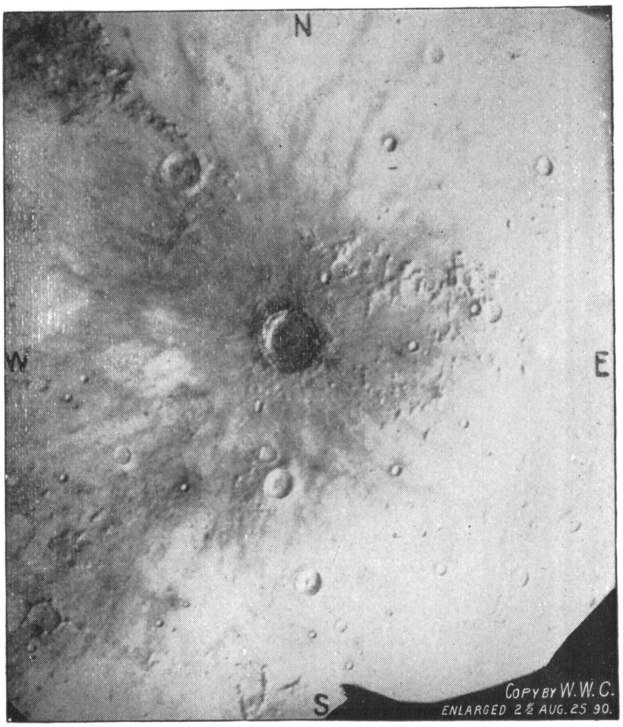
By Edward S. Holden.

The accompanying small figure was made from a negative of the moon taken in the focus of the great telescope on August 25, 1890, at 8 hours, 0 minutes. The original picture of the moon was about five and one-half inches in diameter. A small part of the original showing the lunar crater *Copernicus* has been slightly enlarged and is given in the cut. The scale of the picture is such that the diameter of the whole moon would be about fourteen inches. The diameter of the crater itself is fifty-six miles. The cardinal points, north, south, etc., are indicated on the picture. The original picture is very satisfactory. The representation given here is far less so, but it is the best available. It will probably serve its purpose, however. The other cuts are not enlarged, and show, more or less satisfactorily, the surroundings of this crater.

The walls of the ring-form are not perfectly circular, and they vary somewhat in height at different points.

Their general elevation above the floor of the crater is about eleven thousand feet, rising in places to twelve thousand or even thirteen thousand feet. The slope of the interior terraced wall is far more steep than that of the exterior; and this is a general rule in all such formations on the moon. The average exterior slope

* Reprinted (abridged) from the Californian Magazine, March, 1892.



THE LUNAR CRATER COPERNICUS.

Enlarged from a Negative made with the Great Telescope of the Lick Observatory, August 25, 1890.

of lunar craters is six degrees to seven degrees, while the average interior slope is thirty-five degrees; that is, they are really very gently sloped mounds with a steep-sided pit in the midst. The terraces of the walls deserve careful attention; and, if the cut is examined with a common hand-magnifier, they can be seen a little better.

The floor of the crater is by no means smooth; and from it rise two groups of central peaks, the highest of which is some twenty-four hundred feet. Like all the central peaks of lunar craters, they are much lower than the bounding walls.

Copernicus is surrounded by a mass of mountains, hills and ridges of highly complex structure, and by a marvelous system of brilliant streaks radiating from the crater as a center, and extending in some cases for four hundred miles, or even more, till they meet similar streaks from other craters,—from *Kepler*, *Aristarchus*, etc., which are shown on the cuts following.

This famous lunar mountain has been drawn and described many times. The very best drawings show a number of minor features which are much too small to be represented in the engraving; but no drawing has ever given anything like the true plastic effect, and even the very best drawings fail to show details which are evident on the original photograph.

To make such a drawing at the telescope, the observer must begin by sketching in the forms and shadows accurately, correcting here and adding there, until after one or two nights a skeleton for his finished picture is obtained. By this time the shadows have so changed that most of the work must be put by for a month, until the same phase of illumination recurs.

The next opportunity must be devoted to more corrections and additions, and so on, lunation after lunation, until finally the best possible result is attained. For instance, SCHMIDT'S first recorded observation of *Copernicus* was in 1842 and his last in 1873. And even this best possible result will be highly unsatisfactory. If it is a map it will lack plastic effect; if it is a picture the minor topographical features will necessarily be more or less neglected. It is here that photography becomes of priceless advantage. The preparations for the photograph must be made with the greatest care; the picture must be taken when the atmosphere is steady, clear and transparent; when there is no wind to shake the telescope. But when the right opportunity occurs an exposure of a few tenths of a second is sufficient; and a perma-

nent autographic record of things as they are is obtained. The negative can then be treated in many ways and many differing copies obtained, each one true in itself, but each one bringing out some one point with especial clearness. In the first place it can be enlarged so as to bring out the minor features. It can be "en-smalled" so as to sacrifice the minor details, while the grander relations are made more prominent. Each of these results can again be copied in various manners. A certain exposure given to the copy will produce the best general plastic effect, and it is such copies that are desired by the artist and the general reader. But every single feature on the original has an illumination and a distinctness of its own. If we double or treble, etc., the first exposure, or if we halve it or take a third or even a tenth part of it in making our copies, each of the results will show some special feature or region or relation in a new and in a true light.

In this way the negatives of the Lick Observatory have brought out quite new features,—ruined craters fifty miles in diameter, long streaks and ridges, not suspected or even not perceptible in ordinary visual observation. The key of this method is that the *contrasts* can be artificially (photographically) increased.

If the reader will look at Figure 1 once more, he can probably follow the following identifications. The numbers in parenthesis are the diameters of the craters in miles.

The prominent crater about three-fourths of an inch south of *Copernicus* (56), is *Reinhold* (31), and the next marked feature in the same direction is the crater *Landsberg* (28). Between *Reinhold* and *Copernicus* are two small deep crater-pits close together, A and A[1]. These are, by the way, *precisely* south of the center of *Copernicus*.

The crater half an inch north of *Copernicus* is *Gay-Lussac* (15); and the mountains in which the latter is situated are the lunar *Carpathians*, whose peaks vary from twenty-five hundred to seven thousand feet in altitude. Towards the northwest, about an inch in the picture, is the ring-crater *Eratosthenes* (37). From *Eratosthenes* two spurs of mountains extend, one southwards to the white outlines of the ring-crater *Stadius* (43), the other northwestwards. The region bordering these two spurs and lying towards the southeast is the *Sinus Æstuum*. The eastern wall of *Eratosthenes* is 7,450 feet above the outer surface, and 15,800 feet (the height of Mt. Blanc) above the interior of the crater.

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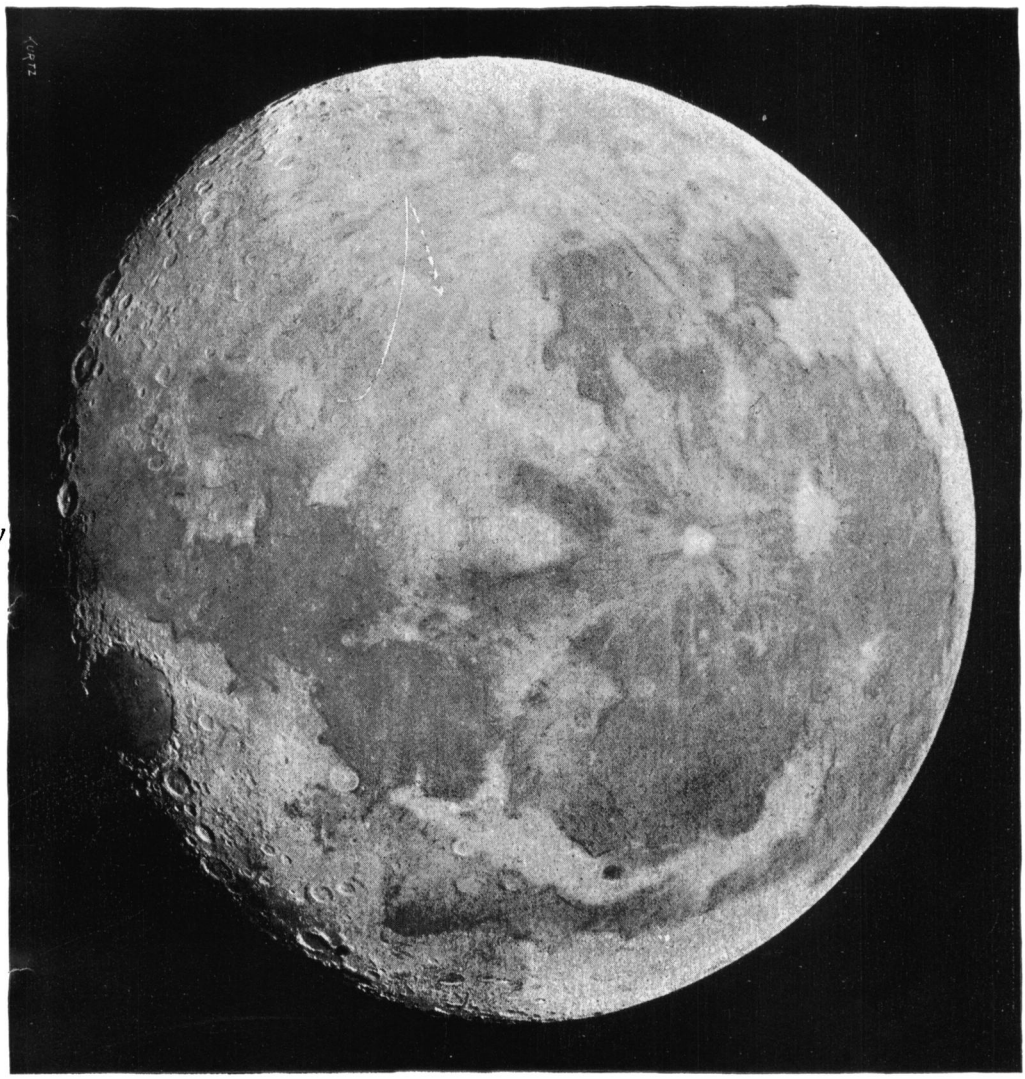

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PHOTOGRAPH OF THE MOON.

Made with the Great Telescope of the Lick Observatory, August 31, 1890, at 14h. 27m.
Moon's Age, 16 days 18 hours.

On the original it is easy to trace a very interesting line of confluent crater-pits, which extends from the southeastern wall of *Stadius* towards the north; this line crosses the direction of the *Carpathians* about half way from *Eratosthenes* to *Gay-Lussac.*

Here then is a line of weakness, and along this line there have been many separate small explosions, each leaving its mark in a crater. The region between this line and the western wall of *Copernicus* is literally filled with such small craters (they cannot be seen in the picture because they are only visible under one particular illumination). They are somewhat like the *fumeroli* of Italian volcanoes, on a larger scale.

The preceding description is necessary to put us in possession of the facts which our picture shows. But the real question now comes: What is the veritable explanation of all this? How shall we conceive to ourselves the process by which these features were formed? What is the relation of these craters to each other; of these bright streaks to the central crater; of the mountain chains, the rows of crater-pits, the interior terraces and hills to the volcanic forces by which they have been created?

If these questions can be answered we shall really know something of the features which so far we have merely viewed. Notwithstanding the immense pains which have been spent in delineations of the particularities of this and other regions of the moon's surface, there is as yet no general and satisfactory answer. We seem to be awaiting some observer who must be at once an astronomer and a geologist, and who will devote his whole life to the geology of the moon. Even the most fundamental questions are not settled. We have called *Copernicus* a "crater," that is, *the* crater of a lunar volcano. Some of the best authorities doubt whether it is a true crater at all.

As with this, so with other questions. Many, indeed most of them, are in doubt; and it is certain that they will not all be definitely settled until the advent of our geologist-astronomer, who may not yet be born.

Under these circumstances, it will not be impertinent if I try to express the convictions to which my own observations of this particular region have led me, especially if I do this with the necessary reserves, and with an apology in advance for any failures to properly interpret the geological evidence. No one can examine these wonderful structures without forming *some* idea as to their nature, and my own is somewhat as follows:

In the first place it is obvious at a glance that *Copernicus* is the dominating feature in the landscape. The surrounding ridges, crater-pits and bright streaks radiate from and depend on this central crater precisely as the corresponding features depend upon *Mauna Loa*. Its vast mouth (56 miles in diameter) is, in fact, a crater,—one crater, or rather a caldera. Sometime in the past, vast explosions of steam and lava have blown out this immense cavity and left these bounding walls somewhat as they are now. We must recollect that the volcanic forces on the moon have been far more violent than they are now on the earth. We have to remember too that the surface of the moon as we see it in this picture is but a single phase of the history of this landscape. There were other volcanoes at this place centuries before *Copernicus* was formed, some of which can even now be traced; and we are only looking at the very last act of a long drama. Underneath the floor of *Copernicus* pipes were leading directly to the living fires below; and the interior lavas were continually rising and falling in these pipes, seeking for outlets through cracks in the mountain side, along lines of weakness everywhere, even overflowing the rim of the crater at times. When the level of the lava in the interior was high it would overflow the floor of the crater and would soon cool. If another vent was found at a lower level, through a crack in the mountain side, the lava in the pipes would sink and leave the floor unsupported except at its edges where it joined the walls. In time the floor would break off all around the rim and fall, leaving a terrace to mark its former position. A new rise of lava in the pipes would form a new floor, and this in turn would form a new terrace. Hundreds of these may have been formed, and scores of them may have left no trace; but the terraces we now see are, it seems to me, indubitable proof that this process went on in *Copernicus* almost precisely in the same way that it is even now going on in *Kilauea* in the Sandwich Islands.

There have been scores and scores of central mountains formed within the crater (just as at *Kilauea*). Those that we see now are the last ones. They undoubtedly contain volcanic vents, and at the very end of the volcano's history they poured a sheet of lava over the whole floor of the crater and left it comparatively smooth as it now is.

The original negative shows ridges streaming off in all directions from the outer walls of the crater. Some of these have been

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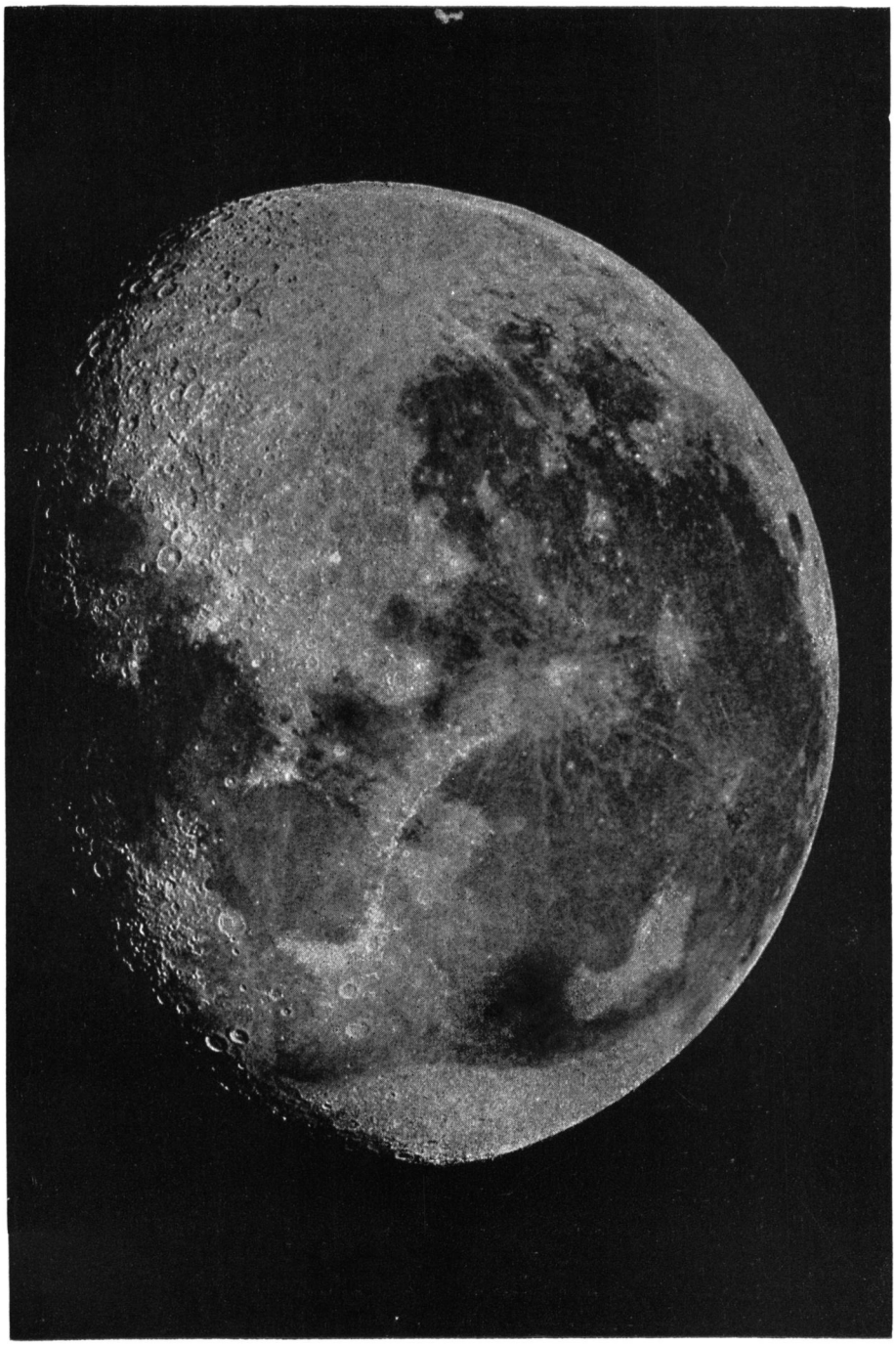

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PHOTOGRAPH OF THE MOON.

Made with the Great Telescope of the Lick Observatory, August 24, 1888.
Moon's Age, 17 days.

formed by elevations of the surface by forces from below, and some of them by lava flowing over the lip of the crater itself, or through cracks in its sides. The bright radiating streaks near *Copernicus* are intimately connected with these ridges. Sometimes the streaks themselves seem to be nothing but very low ridges. In other places they seem to be lava flows which have partially filled up ravines lying between two ridges, or which have followed the direction of earthquake cracks and fissures, forming dikes.

When one is riding across country in the beautiful island of Hawaii and comes to some region which is not covered by dense tropical forests or by luxuriant sugar plantations, his attention is sure to be directed to one of the wonderful lava flows from the great volcanoes of *Mauna Loa* and *Mauna Kea*. He asks his guide, "What is this?" "Oh, this is the lava flow of 1852." Directly he comes to another river of frozen lava,—"And what is this?" "This is the flow of 1881." And so on till in a few days' journey he has crossed a dozen flows all radiating from the central mountain like rivers, all tending towards the sea, and some of them actually reaching it. Now, in Hawaii, history begins with the advent of the missionaries (1820). The larger part of the island is covered with forest and plantation, and therefore is hidden from sight. The action of wind and rain and air disintegrates the lava into soil with amazing quickness; and yet it is impossible for the traveler not to carry away in his mind a picture—a ground plan—of the island as it really is. Here is the central volcanic focus, and the lavas from its interior have built up the whole island mass. On the top of the older lavas, which are carved into ravines and cañons by erosion, lie the radiating lava streams which go in all directions from the center, and which extend even to the sea (thirty-five to forty-five miles). Here are the earthquake cracks and fissures filled up with later lava flows. Here are long tunnels whose broken-down tops leave marked channels,—streaks. Here are rows of confluent crater-pits of all sizes. Here are larger craters like *Kilauea* with subordinate ones like *Kilauea-iki*. Here are huge cracks in the mountain sides where the pressure of the interior lava has broken through.

I do not think that these bright streaks in the moon are volcanic ashes; for I see no reason why they should lie in radiating streaks as they do, unless *all* the streaks were in the bottoms of the cañons, which they are not, as visual observations show.

Again, volcanic ashes should lie in general on the *leeward* side; and I see no evidence that they are not equally distributed. Within the craters are the successive terraces, marking successive levels of the lava flow. The level of the floor of *Kilauea* is to-day more than four hundred feet higher than it was fifty years ago. Some of the older terraces are now submerged, and new ones are in process of formation. Here are the interior cones and mountain masses. In fact every feature which we see in the crater *Copernicus* seems to have its analogue if not its counterpart on this small island of Hawaii.*

If I am straining the analogies, I beg the pardon of my confrères, the geologists;—and I am aware that one of the very best observers of lunar topography has stated most emphatically that such an explanation as this will not serve. It, nevertheless, seems to me to be the true one for the region we are considering, while it certainly will not explain other phenomena of a *somewhat* similar character on other parts of the moon. Such analogies will surely strike any astronomer who travels in Hawaii. The only serious question to my mind is in regard to the difference in scale. In Hawaii we have central craters or *calderas* of two and three miles in diameter, and lava-flows from them of forty miles long which would be much longer if they did not end in the sea. On the moon we have the *caldera* of *Copernicus*, which is fifty-six miles in diameter, with lava-flows of four hundred miles or so. Having regard to the immensely greater effect of volcanic forces on the moon (where the force of gravity, for example, is not more than one-sixth of that on the earth), I confess that I see nothing overstrained in drawing the conclusion that in the volcanoes of Hawaii we now have before our eyes something like a working model of what *Copernicus* once was.

This, then, is what seems to me to be the key to the landscape shown in our engraving; and it gives a kind of unity to its complex confusion and wild variety. There are other regions on the moon far more difficult to understand; but here, at least, it seems that a kind or order can be made to arise out of the chaos.

* I think it is very pertinent to remark that the lavas of Hawaii are much more liquid than those of Italy, for example; and it seems almost safe to hazard the guess that the lavas of the Moon resemble the former rather than the latter.

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PHOTOGRAPH OF THE MOON.

Made with the Great Telescope of the Lick Observatory, November 3, 1890, at 13h. 58m.
Moon's Age, 21 days 5 hours.